ARIZONA NUMERICAL RANKING SYSTEM FOR JURISDICTIONAL DAMS WITH SAFETY DEFICIENCIES

1.0 Introduction

The Arizona Department of Water Resources (ADWR), Dam Safety Section, has a responsibility to protect human life and property from the improper operation or failure of a dam. The Department supervises the safety of over 200 dams in Arizona with limited staff and resources. There is a need for a method of prioritizing dams within its inventory of jurisdictional dams for several purposes including, distribution of loan or grant money to repair dams, internal budgeting, and enforcement action. For this reason, Tetra Tech Inc. and Arizona State University have developed a numerical ranking or prioritizing system for the dams with safety deficiencies within the Department's inventory of dams. Documentation of the development of the system and selected references are included as Appendices in the Tetra Tech, Inc. report titled "Numerical Ranking System for Jurisdictional Dams In Arizona," dated July 2001.

2.0 Process Description

This prioritization-ranking system, modeled after a similar system used by the State of Washington, provides a scoring of dams with safety deficiencies within State jurisdiction based on a consequences of failure category described by the number of persons at risk (PAR) and the number and severity of deficiencies related to typical failure modes. Currently, only dams with High or Significant Hazard Potential Classifications are considered to have safety deficiencies. Very Low and Low Hazard Potential Classifications are excluded because potential economic, lifeline, and intangible losses are low or restricted to the dam owner's property. Five categories of potential failure modes have been delineated. These include: 1) Hydrologic Adequacy, 2) Potential for Piping, 3) Dam Stability, 4) Condition of Outlet Works, and 5) Unique Conditions. A scale ranging from "Satisfactory" to "Severe" describes the seriousness of each identified deficiency. Use of the term "Severe" instead of "Emergency" is a deviation from Washington State terminology for clarification purposes. A true emergency situation falls out of the realm of this ranking scheme, as it requires immediate mitigative action.

The six categories (i.e. PAR and five potential failure modes) constitute a method of simplifying a more complex reality. The scoring gives a relative ranking of one dam to another. This is not an absolute score, nor is it unchanging. The process is a dynamic one. Ultimately, the final ranking of seriousness at a particular time must be confirmed based on the knowledge and judgment of engineers experienced in dam technology as well as additional detailed studies, when deemed appropriate.

The first step in the process of scoring a dam is to gather the available significant information regarding the dam. The information is reviewed and the number of persons at risk as well as the conditions at the dam are summarized on the Basic Information Summary Work Sheet (pages 7 & 8). This step, performed by a qualified engineer experienced in dam technology, is completed prior to any scoring of the dam. A USGS quadrangle map showing the dam is desirable. The most recent inspection report, the most recent safety deficiency letter, and executive summaries or other significant information from previous studies and/or Phase I type inspections should also be reviewed and listed on the Basic Information Summary Work Sheet as references. This information documents the considerations incorporated into the scoring and ranking.

The second step is to compare the information from the files compiled on the Basic Information Summary Work Sheet with the Scoring Descriptions for Category I (Page 9) as well as Categories II.A. – II.E. (Pages 10 – 17) and to assign (score) points in accordance with these descriptions. The categories are described in more detail in the following section. The conditions described in the Category II scoring descriptions are presented as guidelines. Deficiencies, which are not explicitly described in the scoring descriptions, should be assigned points in a manner consistent with the seriousness relative to those conditions described. For those dams where a deficiency is suspected but its seriousness is unknown, points should be awarded based on engineering judgment in the category of concern until further evaluation is possible. A Scoring Summary Work Sheet is provided to allow a gathering of the scores for the dam onto one sheet (Page 18).

The worst-case condition for each category dictates the score and only one score can be given to each category. Some safety deficiencies could be described by more than one category. In these instances, points should be allotted in one category only, so as to not double-count the deficiency. Once each category has been scored, a total score for the dam is calculated.

Total ranking points for each dam are determined by adding the PAR points to the potential failure mode deficiency points on the Scoring Summary Work Sheet. In recognition of the fact that the risk associated with a single “Major” or “Severe” deficiency is much higher than that associated with the summation of numerous “Minor” or “Moderate” deficiencies, the final point total is divided in half when no deficiency category exceeds the “Minor” or “Moderate” level.

The deficiency categorizations and point allocations contained within this ranking system were developed for the narrow purpose of developing relative rankings of dams with safety deficiencies. The system gives higher priority to the repair of dams in immediate distress versus those with deficiencies related to the occurrence of extreme events (i.e. large floods and earthquakes). The numerical point totals are not intended to represent the absolute levels of hazard or risk associated with each dam and should not be used as criteria for establishment of Unsafe Dam classifications.

Given the inherent uncertainty in the information used and the repeatability of the application of the category descriptions, point totals differing by less than a moderate deficiency (i.e. 65 points) may be considered equivalent. After an initial ranking identifies a group of similarly scored dams near the top, more detailed studies and subsequent re-ranking of just these dams can be used for refinement of the rankings. In any event, the numerical ranking is used as a starting point, after which additional studies or other project specific non-technical intangibles may be incorporated into the decision making process.

3.0 Category Descriptions

The category descriptions are provided below to give guidance and consistency to those scoring the dams. Some explanatory comments on the descriptions are also included.

3.1 Section I – Consequences of Failure

Category I. Persons at Risk (See Page 9)

In as much as loss of life is the single most important consequence of a dam failure, Persons at Risk (PAR) is used as the surrogate measure of consequence in this system. PAR is the number of people, who without evacuation, are within the area of an inundation flood of certain defined criteria of depth and/or velocity due to dam failure during the Inflow Design Flood (IDF) including discharges from the outlets and spillways. The Bureau of Reclamation has published detailed information on the hazards posed by various combinations of floodwater depth and velocity in their 1988 document *Downstream Hazard Classification Guidelines, ACER Technical Memorandum No. 11*. Based on this information, the Arizona Ranking System establishes criteria of a depth of greater than one foot and/or a velocity greater than two feet per second for defining the inundation area.

It is commonly assumed that each permanent dwelling has three occupants. Site-specific information about the likely occupancy should be used at worksites and temporary use facilities such as resorts, campsites, and recreational areas. Those situations where PAR is not an adequate measure of the consequences of a failure can be adjusted as a unique condition (See Category II.E.).

Not all dams have had a dam break analysis performed at this time. Remember that for this scoring, the lines of demarcation may be such that it is very clear which category applies. In the event that a question exists, one of several simple methods may be applied. These are described in Preliminary Safety Evaluation of Existing Dams, prepared for FEMA by Stanford University, December 1984. The Simplified Dam Break program (NWS) is probably the most used of the methods.

3.2 Section II – Potential Failure Modes and Seriousness of Deficiencies

3.2.1 Category II.A. Hydrologic Adequacy (See Page 10)

Hydrologic adequacy is measured in terms of the size of the flood, as a percentage of the Probable Maximum Flood (PMF), which results in an overtopping depth greater than the defined critical value. In the absence of site-specific information regarding the critical depth of overtopping, simplified estimates based on the type and condition of the dam are provided. These estimates are adopted from information presented in the 1983 Stanford/FEMA document, *Preliminary Safety Evaluation of Existing Dams*, and the 1997 Bureau of Reclamation Risk Based Profile System. The severity of the safety deficiency is related to the magnitude of the IDF of the dam under consideration. Arizona Rules for Dam Safety prescribe the magnitude of the IDF to vary with size and hazard classification. Arizona Rules for Dam Safety do not specifically define the IDF for high hazard potential dams. The Rule states, "*For a high hazard potential dam, the applicant shall design the dam to withstand an inflow design flood that varies from .5 PMF to the full PMF, with size increasing based on persons at risk and potential for downstream damage. The applicant shall consider foreseeable future conditions*." (AAC 12.15.1216. A. 2.) ADWR criteria for High Hazard Dams are thus established as follows:

> In accordance with A.A.C. R12-15-1216 (A)(2), the inflow design flood (IDF) for high hazard potential dams shall be the full probable maximum flood (PMF) if the persons at risk (PAR) is more than 300; the IDF shall be 0.75 PMF if the PAR is between 31 and 300; and the IDF shall be 0.5 PMF if the PAR is less than 31. The IDF shall be increased from 0.5 PMF or 0.75 PMF if there is a high potential for extensive downstream damage and/or severe disruption of critical lifeline services.

The IDF criteria for High Hazard Potential Dams was developed based on the results of a review of the criteria used by other agencies. Supporting documentation is presented in Appendix B.

3.2.2 Category II.B. Potential for Embankment or Foundation Piping (See Page 11)

This category description is intended to address all issues relating to the potential for piping failures in embankment dams and/or in foundations. It includes cracks or other potential flow paths that may exist or be developing through or under a dam. Cracking of embankments or concrete, animal burrows, detrimental vegetation, flows along poor construction joints, poor abutment contacts, and flow paths along any penetrations through the dam should all be considered.

Appropriate filter design is important to resist piping and is an important consideration. In general, dams designed prior to1960 did not include filters. Dams constructed between 1960 and 1985 may have filters that do not meet current standards. The current standards were developed though testing in the early 1980's. Arizona Dam Safety Rules require "*The design of any significant or high hazard potential dam shall provide seepage collection and prevent internal erosion or piping due to embankment cracking or other causes.*" (AAC 12.15.1216. B. 3.)

Studies by Leonards, and Narain indicate that embankment dams constructed of silt or silty sand material are more susceptible to cracking. (Leonards, and Narain, "Flexibility of clay and cracking of earth dams," ASCE SM 2 March 1963)

3.2.3 Category II.C. Dam Stability (See Pages 12 – 15)

This category includes three description sections, the Embankment Dam Static Stability section, the Concrete and Masonry Dam Static Stability section, and the Seismic Stability section. As with all categories, the worst-case stability condition (i.e. static or seismic) governs the score assigned for the overall category.

The <u>Embankment Dam Static Stability</u> section describes the factors that relate to the stability of an embankment dam under static loading conditions. In those cases where no stability calculations are available, a first cut analysis can be made by comparing the dam with the suggested safe slopes found in the USBR Design of Small Dams, 1987 (Figures 6.5 and 6.6), included on Page 13.

If the dam is a concrete or masonry dam, the <u>Concrete and Masonry Dam Static Stability</u> section addresses the issues that would be considered <u>instead of</u> those listed in the Embankment Dam Static Stability section.

The Seismic Stability section addresses seismic stability for all dams. The deficiency categories are each divided into three subcategories; (1) A seismic stability analysis has been performed, (2) An embankment dam for which no analysis has been performed, and (3) A concrete or masonry dam for which no analysis has been performed. In order to lend higher priority to the repair of dams in immediate distress versus those with deficiencies related to the occurrence of earthquake events, the “Major” and “Severe” deficiency categories are reserved for static loadings only.

In the absence of a site-specific study, a preliminary evaluation of seismic risk is made using the “Map of Horizontal Acceleration at Bedrock for Arizona with 90 Percent Probability of Non-Exceedance in 250 Years,” by Euge, K. M., Schell, B. A., and Lam I. P., 1992, developed as part of an Arizona Department of Transportation sponsored research study. The acceleration values associated with this map have a return period of about 2500 years.

3.2.4 Category II.D. Condition of Outlet Conduit (See Page 16)

The category descriptions and conditions are adapted from a paper presented at the 1989 ASDSO Annual Conference, titled, “Evaluation of the Condition of Principal Spillway Conduits,” written by Koeliker, Lin and Best. The evaluation described in the paper is based on observations made within each outlet with a camera. In the event that such photographs are not available at the time of the scoring, engineering judgment must be applied based on all other observations that are available.

Ranking points allocated in this category relate only to the physical condition of the outlet conduit. In the event of seepage occurring along the outside of the conduit, points should be allocated in *Potential for Embankment or Foundation Piping Category* as is the case for uncontrolled seepage along any penetration.

3.2.5 Category II.E. Unique Conditions (See Page 17)

Unique conditions should be only those conditions that cannot be incorporated within one of the other categories. The word “Unique” has the following synonyms: only one of its kind, sole, exclusive, exceptional, distinctive, and rare. This category gives the person scoring the dam an opportunity to add points for some of these situations or conditions.

The following examples are conditions that may be considered unique:

- Potential landslides or other deficiencies within the reservoir boundaries,
- Regional or local ground subsidence,
- Inadequate outlet discharge capacity,
- Spillway flow passing over or encroaching on dam,
- Vandalism,
- Downstream valve control in an embankment dam,
- Potential extreme lifeline losses, or
- Irreplaceable intangible losses.

Ranking points should be applied based on seriousness of the deficiency in a manner consistent with points allocated in other categories. Examples of possible unique conditions and recommended ranges of points are provided for assistance.

4.0 Point Tabulation

Total Ranking Points are determined for each dam by adding the Consequences of Failure (PAR) points to the Potential Failure Modes Deficiency points on the Scoring Summary Work Sheet as shown below.

Section I. Consequences of Failure			
	Category I	Persons at Risk	Points
Section II. Potential Failure Modes and Seriousness of Deficiencies			
	Category II.A.	Hydrologic Adequacy	Points
	Category II.B.	Potential for Piping	Points
	Category II.C.	Dam Stability	Points
	Category II.D.	Outlet Conduit	Points
	Category II.E.	Unique Conditions	Points
			Total Points

In the event that none of the identified deficiencies exceed the level of "Minor" or "Moderate," the final point total is multiplied by a factor of 0.5.

5.0 Attachments

1. Ranking of Dams, Basic Information Summary Worksheet (Two pages)
2. Ranking of Dams, Category Scoring Descriptions (Nine pages)
3. Ranking of Dams, Scoring Summary Worksheet (One page)

RANKING OF DAMS
BASIC INFORMATION SUMMARY WORK SHEET (1of 2)

(Enter data from files and other information available on the dam.)

Dam Name **ID no.** **Date** **Engineer**

Date last inspected: _________________ (Attach report) Hazard Potential Class: (circle) H S

Type:________________ Safety status: (circle) Unsafe Safety Deficiency Satisfactory

Height: _______(ft) Storage Capacity:_____________ (ac. ft.) Size Class (circle) S I L

Year Completed _______________Latitude: ___________ Longitude: ____________ Drainage Area: ____________

Downstream Community: __________________ Dist. ______(mi)

Section I. CONSEQUENSES OF FAILURE

Category I. Persons at Risk (PAR)

PAR is the number of people, who without evacuation, are within the area of an inundation flood of a depth of greater than one foot and/or a velocity greater than two feet per second due to dam failure during the Inflow Design Flood (IDF) including discharges from the conduits and spillways. PAR includes persons at permanent dwellings, worksites, and temporary use areas.

The only delineation necessary is between (a) Zero PAR, (b) 1 to 3 PAR, (b) 4 to 30 PAR, (c) 31 to 300 PAR, and (d) more than 300 PAR.

If an inundation study has been completed, use the information provided and list study date and the person or engineering firm performing the study. If no study has been completed use simplified dam break or some other approximate method. In many cases it may be acceptable to make the necessary delineation by observation.

Circle one :

0 PAR	1 – 3 PAR	4 – 30 PAR	31 – 300 PAR	More than 300 PAR

Comments:

List studies:

Section II. POTENTIAL FAILURE MODES AND SERIOUSNESS OF DEFICIENCIES
(Use inspection reports and studies as a guide to describe conditions at the dam (deficiencies)

Category II.A. Hydrologic Adequacy

Inflow Design Flood (IDF):
Describe present spillway capacity in percent of PMF if available: %
Other information on the spillway:

RANKING OF DAMS
BASIC INFORMATION SUMMARY WORK SHEET (2of 2)

(Enter data from files and other information available on the dam.)

Dam Name	ID no.	Date	Engineer

Category II.B. Potential for Piping Failure Describe quantity of seepage. Is it consistent with design? Is piping evident?

Category II.C. Dam Stability

Steady State Seepage Factors of Safety:
Upstream (partial pool) ______________ and downstream (full pool) ______________

Seismic: Peak Ground Acceleration (PGA) from ADOT Map = % of g.

Category II.D. Outlet Conduit (Describe construction method, seepage protection, cracking, corrosion, lining and joints, etc.)

Category II.E. Unique Conditions (Describe all conditions qualifying as sole, exceptional, only one of its kind, distinctive, and/or rare. Such conditions do not fit into any other category but may have significant impact on the potential for failure or damage downstream in the event of a failure.)

RANKING OF DAMS
CATEGORY SCORING DESCRIPTIONS

CATEGORY I. PERSONS AT RISK (PAR)

PAR is the number of people, who without evacuation, are within the area of an inundation flood of a depth of greater than one foot and/or a velocity greater than two feet per second due to dam failure during the Inflow Design Flood (IDF) including discharges from the conduits and spillways. PAR includes persons at permanent dwellings, worksites, and temporary use areas.

It is commonly assumed that each permanent dwelling has 3 occupants. Site-specific information about the likely occupancy should be used at worksites and temporary use facilities such as resorts, campsites, and recreational areas.

	Description
0 points	Zero persons at risk
200 points	1 to 3 persons at risk
300 points	4 to 30 persons at risk
400 points	31 to 300 persons at risk
500 points	More than 300 persons at risk

RANKING OF DAMS
CATEGORY SCORING DESCRIPTIONS

CATEGORY II.A. HYDROLOGIC ADEQUACY

Matrix for Evaluating Seriousness of Dam Deficiencies
(The worst condition governs in the overall rating for Category II.A.)

Step 1: Estimate the critical overtopping depth, d_c, for the dam under consideration.

Type of Dam	Condition	d_c [ft]
Concrete Gravity	Good Condition – Very little seepage No crack or movement	$(Height)^{0.6}$
	Fair Condition – Moderate seepage Small structural cracks Slight differential movement	$(Height)^{0.45} - 1$
	Poor Condition – Excessive seepage Large continuous cracks Excessive differential movement	$(Height)^{0.3} - 2$
	Poor foundation condition, i.e. especially vulnerable to overtopping	Zero
Thin Arch or Buttress	See Concrete Gravity	Value calculated for Gravity Dam divided by two
Embankment	Inadequate erosion protection	Zero
	Erosion protection	1

Note: Based on Preliminary Safety Evaluation of Existing Dams, Stanford/FEMA, 1983, and the 1997 Bureau of Reclamation Risk Based Profile System.

Step 2: Determine the percentage of the PMF required to cause an overtopping depth, d_o, which exceeds the d_c estimated in Step 1.

Step 3: <u>IDF is greater than or equal to 0.5 PMF:</u> Compare the percentage of the PMF obtained in Step 2 to the ranges provided in the table below for the appropriate IDF and allocate the points shown.

<u>IDF is 0.25 PMF:</u> If the percentage of the PMF obtained in Step 2 is less than 25 then allocate 145 points.

	IDF		
	0.5 PMF	**0.75 PMF**	**PMF**
Satisfactory **0 points**	More than 50% of PMF	More than 75% of PMF	More than 100% of PMF
Minor **20 points**	45% to 50% of PMF	63% to 75% of PMF	80% to 100% of PMF.
Moderate **65 points**	40% to 44% of PMF	50% to 62% of PMF	60% to 79% of PMF
Major **145 points**	25% to 39% of PMF	25% to 49% of PMF	25% to 59% of PMF
	Or, spillway channel or control is highly eroded.		
Severe **300 points**	Less than 25% of the PMF. Or, spillway is highly erodible and likely to result in sudden release of reservoir.		

Step 4: If the spillway is highly eroded or likely to fail structurally, then allocate points as described in the above table if they are greater than the points that result from Step 3.

RANKING OF DAMS
CATEGORY SCORING DESCRIPTIONS

CATEGORY II.B. EMBANKMENT and FOUNDATION PIPING

Matrix for Evaluating Seriousness of Dam Deficiencies
(The worst condition governs in the overall rating for Category II.B.)

	Description
Satisfactory **0 points**	No signs of defects or distress of embankment or foundation. Seepage is in agreement with design expectations. Adequate filter drain system (including conduit filter diaphragm) exists. No trees or deep-rooted vegetation on the embankment or within toe area.
Minor **20 points**	Evidence of minor defects, such as burrow holes and/or localized deep-rooted vegetation. Minor uncontrolled clear seepage and no evidence of internal erosion. Embankment constructed with fine silty sand or non-dispersive clayey silt material. Filter drain system adequacy unknown.
Moderate **65 points**	Numerous shallow (< 2 feet deep) burrow holes and/or cracks on one or both slopes and/or crest of embankment. Shallow-rooted trees less than 6 feet tall and less than 4 inches in diameter on the embankment or within toe area. Embankment constructed on unconsolidated alluvial, limestone, or gravel foundation without cutoff or key. Embankment filter drain system (including conduit filter diaphragm) is nonexistent or inadequate. Geotextiles used a sole defense against dam failure. Evidence of poor embankment compaction or poor or inadequate bond to foundation and abutments. Moderate uncontrolled clear seepage and no evidence of internal erosion.
Major **145 points**	Embankment, foundations, or abutments with large or deep-rooted trees, isolated deep sinkholes and/or animal borrows. Extensive hairline transverse embankment cracking (< 2 feet deep) in absence of adequate filter drain. Significant uncontrolled clear seepage and no evidence of internal erosion. Significant differential settlement of portions of the embankment.
Severe **300 points**	Embankment, foundations, or and abutments with extensive open cracks (≥ ¼” wide and > 2 feet deep), numerous deep sink holes and/or large-animal borrows. Significant concern for or evidence of piping (i.e. internal erosion) and/or sand boils. Abrupt changes in seepage. Subsidence crack through embankment or abutment.

RANKING OF DAMS
CATEGORY SCORING DESCRIPTIONS

CATEGORY II.C. DAM STABILITY
1. EMBANKMENT DAMS (STATIC STABILITY)

Matrix for Evaluating Seriousness of Dam Deficiencies
(The worst condition governs in the overall rating for Category II.C.)

	Description
Satisfactory **0 points**	No signs of defects or distress of embankment or foundation. Movement is in agreement with design expectations. Pore pressures, if known, are consistent with design.
Minor **20 points**	Some evidence of minor defects, such as minor erosion of the slopes. Embankment constructed with silt or sandy silt material.
Moderate **65 points**	Numerous shallow (less than 2 feet deep) erosion gullies on one or both slopes and/or crest of embankment. Embankment constructed on unconsolidated alluvial foundation. Evidence of poor embankment compaction or poor or inadequate bond to foundation and abutments, which may lead to embankment movement. $1.3 \leq$ Computed Factor of Safety < 1.5 [Steady state seepage: upstream (partial pool) and downstream (full pool)]. If no FS has been computed, D/S slopes are steeper than prescribed by Table 6.5 or Table 6.6, Design of Small Dams, USBR 1987 (Tables included on next page).
Major **145 points**	Distressed embankment, foundations, or abutments. $1.0 \leq$ Computed Factor of Safety < 1.3 [Steady state seepage - Upstream (partial pool) and downstream (full pool)]. Evidence of pore pressures significantly higher than design values.
Severe **300 points**	Unusual and sudden change in pore pressure information. Misalignment, sloughing or bulging of embankment. Evidence of heave on downstream slope. Tilting of the crest, deep longitudinal tension cracks. Movement of the outlet conduit. Computed Factor of Safety < 1.0 [Steady state seepage - Upstream (partial pool) and downstream (full pool)].

Table 6.5 from Design of Small Dams, USBR 1987
(For Homogeneous Dams on stable foundation*)

Case	Type	Purpose	Subject to rapid drawdown	Soil class	Upstream Slope - No steeper than:	Downstream Slope - No steeper than:
A	Homogeneous or modified Homogeneous	Detention or Storage	No	GW, GP, SW, SP	Pervious	Unsuitable
				GC, GM, SC, SM	2.5:1	2:1
				CL, ML	3:1	2.5:1
				CH, MH	3.5:1	2.5:1
B	Modified Homogeneous	Storage	Yes	GW, GP, SW, SP	Pervious	Unsuitable
				GC, GM, SC, SM	3:1	2:1
				CL, ML	3.5:1	2.5:1
				CH, MH	4:1	2.5:1

**Dams constructed on soft foundations require special consideration*

Table 6.6 from Design of Small Dams, USBR 1987
(For Zoned Dams on stable foundation*)

Type	Purpose	Subject to rapid drawdown	Shell Material Classification	Core Material Classification	Upstream Slope - No steeper than:	Downstream Slope - No steeper than:
Zoned with minimum core A	Any	Not critical	Rockfill, GW,GP, SW (Gravelly) SP (Gravelly)	GC, GM, SC, SM, CL, ML, CH, MH	2:1	2:1
Zoned with Maximum Core	Detention or Storage	No	Rockfill, GW,GP, SW (Gravelly) SP (Gravelly)	GC, GM, SC, SM, CL, ML, CH, MH	2:1 2.25:1 2.5:1 3:1	2:1 2.25:1 2.5:1 3:1
Zoned with Maximum Core	Storage	Yes	Rockfill, GW,GP, SW (Gravelly) SP (Gravelly)	GC, GM, SC, SM, CL, ML, CH, MH	2.5:1 2.5:1 3:1 3.5:1	2:1 2.25:1 2.5:1 3:1

**Dams constructed on soft foundations require special consideration*

RANKING OF DAMS
CATEGORY SCORING DESCRIPTIONS

CATEGORY II.C. DAM STABILITY
2. CONCRETE or MASONRY DAMS (STATIC STABILITY)

Matrix for Evaluating Seriousness of Deficiencies
(The worst condition governs in the overall rating for Category II.C.)

	Description
Satisfactory **0 points**	Good condition, only minor or no unusual cracking, spalling, scaling pop-outs or movements observed but not considered to be of structural significance.
Minor **20 points**	Only minor seepage. Seepage is clear, measured and not increasing over time. Dam has no system for monitoring movement.
Moderate **65 points**	Design strength of concrete unknown. Design information unavailable. Seepage is unmeasured and clear. Very small structural cracks that appear to be localized about highly stressed areas (such as abutments). Localized surficial weakness of structural concrete due to degradation, spalling, or alkali aggregate reaction.
Major* **145 points**	Extensive evidence of concrete weakness due to degradation, spalling, or alkali aggregate reaction. Binding of gates and valves and/or deformations in conduits or interior access tunnels. Evidence of structural cracking. Insitu strength unknown or questionable. Heavy seepage from lift lines, abutments or cracks. Seepage may carry fines. Abutment distress or instability (e.g. rockfall) in case of arch dams.
Severe* **300 points**	Deformation and/or differential movements greater than anticipated in design. Large continuous structural cracks. Localized crushing, bending or buckling of concrete. Opening of construction joints. Excessive or increasing seepage at lift lines, abutments or cracks. Severe scaling, large pop-outs, and spalling.

**A closer structural examination may be required for delineation between "Major" and "Severe" deficiency ratings.*

RANKING OF DAMS
CATEGORY SCORING DESCRIPTIONS

CATEGORY II.C. DAM STABILITY
3. ALL DAM TYPES (SEISMIC STABILITY)

Matrix for Evaluating Seriousness of Deficiencies
(The worst condition governs in the overall rating for Category II.C.)

	Description
Satisfactory **0 points**	Analysis indicates adequate seismic stability under design load, liquefaction of embankment and foundation unlikely.
	If no analysis, embankment well compacted, dam founded on stable foundation and/or Peak Ground Acceleration[1] (PGA) ≤ 0.15g.
	If no analysis, concrete or masonry dams with PGA ≤ 0.2g.
Minor **20 points**	Analysis indicates marginal seismic stability and/or deformation results in loss of freeboard (D ≤ freeboard) and/or isolated limited zones of liquefaction of embankment or foundation under design load.
	If no analysis, saturated alluvial foundation or embankment is not well compacted and PGA > 0.15g.
	If no analysis, concrete or masonry dams with 0.2g < PGA ≤ 0.25g.
Moderate[2] **65 points**	Analysis indicates inadequate seismic stability, excessive deformation (D > freeboard) and/or widespread liquefaction of embankment or foundation under design load.
	If no analysis, loose, saturated alluvial foundation or embankment with high pore pressures is not well compacted and PGA > 0.15g.
	If no analysis, concrete or masonry dam with PGA > 0.25g.

Note[1]: Peak Ground Acceleration (PGA) obtained from site-specific studies or "Map of Horizontal Acceleration at Bedrock for Arizona with 90 Percent Probability of Non-Exceedance in 250 Years," by Lam I. P., Schell, B. A., and Euge, K. M., 1992, ADOT Report No. AZ92-344.

Note[2]: In order to give higher priority to the repair of dams in immediate distress versus those with deficiencies related to the occurrence of earthquake events, the "Major" and "Severe" CATEGORY II.C. deficiency delineations are reserved for static loadings only.

RANKING OF DAMS
CATEGORY SCORING DESCRIPTIONS
CATEGORY II.D. OUTLET CONDUIT
Matrix for Evaluating Seriousness of Deficiencies
(The worst condition governs in the overall rating for Category II.D.)

	RATING[1]	CRACKS	CORROSION	LINING	JOINTS
Satisfactory **0 Points**	9	None; new condition	None; new condition	No loss, new condition	Watertight; gaps well within tolerance
	8	If any they are hairline and of no structural concern	Very little	Slight evidence of abrasion, scouring, cracking or spalling	No evidence of seepage at any joint; gaps within tolerance
Minor **20 points**	7	Minor and free of leaks or evidence of leakage	Minor, no obvious loss of material evident	Minor evidence of abrasion, scouring, cracking , or spalling	One or more show signs of minor leakage; gaps within tolerance
Moderate[2] **65 points**	6	Less than 1/8" and show only minor evidence of leakage	Some deterioration of material evident	Some loss to the point that underlying material is exposed at several locations	One or more have signs of leakage and/or deterioration; gaps within tolerance
	5	Less than 1/4" and show evidence of leakage	Significant deterioration at one or more locations evident	Missing on parts of the conduit through the length	One or more show evidence of leakage and/or deterioration; gaps within tolerance
Major **145 points**	4	Large enough to show considerable evidence of leakage	Deterioration to point of concern for long-term structural integrity of conduit	Loss so substantial that there is concern for the durability of the underlying material	One or more is leaking and/or significantly deteriorated; gap exceeds tolerance
	3	Openings large enough to affect the integrity of the embankment	Corroded to the point of leakage expected at one or more locations	No longer effective throughout the conduit	Leak large enough to affect embankment; gap well beyond tolerance
Severe **300 points**	2	Embankment is being affected by allowing erosion of the embankment	Corroded so much that leaks are evident	Completely missing	Embankment exposed at one or more joints; alignment of sections affected
	1	Flow occurring outside the conduit as well as inside	Corrosion so substantial that structural integrity of conduit is in question	-----	Water freely flowing though joints as freely as in the conduit; ends no longer line up
	0	Conduit no longer main path of flow because of losses through cracks	So much material lost to corrosion that conduit is no longer capable or supporting the fill	-----	-----

Note[1]. KSU Ratings for Conduits from Table 1 of "Evaluation of the Condition of Principal Spillway Conduits," Koelliker, et al. 1989, ASDSO Conf.

Note[2]: The presence of a corrugated metal pipe (CMP) outlet is treated as a Moderate Deficiency.

RANKING OF DAMS
CATEGORY SCORING DESCRIPTIONS

CATEGORY II.E. UNIQUE CONDITIONS

Matrix for Evaluating Seriousness of Deficiencies
(The worst condition governs in the overall rating for Category II.E.)

A unique condition must qualify as sole, exceptional, only one of its kind, distinctive, and/or rare. Such conditions do not fit into any other category but may have significant impact on the potential for failure or damage downstream in the event of a failure.

Ranking points should be applied based on seriousness of the deficiency in a manner consistent with points allocated in other categories. Examples of possible unique conditions and recommended ranges of points are provided below.

	Recommended Point Assignments			
Example of Possible Unique Conditions	**Minor 20 points**	**Moderate 65 points**	**Major 145 points**	**Severe 300 points**
Vandalism of outlet works occurs regularly	X	X		
Reservoir rim has active landslide with significant volume compared to reservoir volume			X	X
Inadequate outlet discharge capacity to drain reservoir within short period of time	X	X	X	
Emergency spillway located on embankment dam	X	X	X	X
Emergency spillway discharge encroaches on dam	X	X	X	X
Downstream valve control in an embankment dam		X	X	
OTHER	X	X	X	X

RANKING OF DAMS
SCORING SUMMARY WORK SHEET

(Use Basic Information Summary Worksheet and Category Scoring Descriptions for each Category)

Dam Name **ID no.** **Date** **Engineer**

Section I. CONSEQUENCES OF FAILURE

Category I. Persons at Risk (PAR) (For scoring see page 9)**:**

Zero PAR	1 – 3 PAR	4 – 30 PAR	31 – 300 PAR	> 300 PAR	Score
0 points	200 points	300 points	400 points	500 points	

Section II. POTENTIAL FAILURE MODES AND SERIOUSNESS OF DEFICIENCIES

Category II.A. Hydrologic Adequacy (For scoring see page 10)**:**

Satisfactory	Minor	Moderate	Major	Severe	Score
0 points	20 points	65 points	145 points	300 points	

Category II.B. Potential for Piping Failure (For scoring see page 11)**:**

Satisfactory	Minor	Moderate	Major	Severe	Score
0 points	20 points	65 points	145 points	300 points	

Category II. C. Dam Stability (For scoring see pages 12 – 15)**:**

Satisfactory	Minor	Moderate	Major	Severe	Score
0 points	20 points	65 points	145 points	300 points	

Category II. D. Outlet Conduit (For scoring see page 16)**:**

Satisfactory	Minor	Moderate	Major	Severe	Score
0 points	20 points	65 points	145 points	300 points	

Category II. E. Unique Conditions (For scoring see page 17)**:**

Satisfactory	Minor	Moderate	Major	Severe	Score
0 points	20 points	65 points	145 points	300 points	

	Total Score
Total score equals the sum of all category scores with only one score for each category.	

	0.5 × Total Score
If all deficiencies rated minor and/or moderate, multiply Total Score by 0.5.	